CHAPTER 2 Force & Newton's laws of motion

Human life would be dull without social interactions. Similarly, the physical universe would be dull without physical interactions. Social interactions with friends and family change our behaviour; physical interactions change the "behaviour" (e.g. motion) of matter. An interaction between two objects can be described and measured in terms of two forces, one exerted on each of the two interacting objects. A force is a push or pull that one object exerts on another.

2.1 Kinds of forces

- Force can be classified in many ways. For example, force can be divided in two kinds :

  (1) Continuous forces (2) Momentary forces

Continuous forces

A force constantly applied to an object is called a continuous force. There are many examples of continuous forces. The downward force of Earth's gravity on all objects is a continuous force called weight. All the automobile engines, aeroplane engines, rocket engines provide continuous forces to run them continuously.

Momentary forces

Not all forces are continuous. A moving object sometimes collides with another object, causing a change in speed or direction. This is called a momentary force.

A force applied to an object for a moment only is called a momentary force.

One example of a momentary force is when a cricket player hits a cricket ball with a bat. First, the bowler throws the ball toward the batsman. Then, the batsman swings the bat. When the bat makes contact with the ball, the momentary force applied by the bat causes the ball to move in another direction. The force applied by the bat is limited and does not keep continuously acting on the ball. However, it is important to remember that other forces, such as gravitational force, do act on the ball continuously.

- Force can also be divided in two kinds :

  (1) Contact forces (2) Non-contact force (or action-at-a-distance forces).

Contact forces

When you press the keys on a computer keyboard, your fingers exert a force on the keys. This force can be exerted only when your fingers are touching the keys.

A force that is exerted only when two objects are touching is a contact force.

A contact force can be small, such as the force you exert to push a pencil across a sheet of paper, or large, such as the force exerted by a traffic crane as it pulls a car along a street. Contact forces include muscular forces, tension, friction, normal forces.

Non-contact force (Action-at-a-distance force)

When you jump up in the air, you are pulled back to the ground, even though nothing seems to be touching you. Forces can be exerted by one object on another even though they aren't touching each other. The force pulling you down to Earth is the gravitational force exerted by Earth. This force is a non-contact force.

A non-contact force is a force that one object exerts on another when they are not touching. Non-contact forces include the gravitational force, the electric force, and the magnetic force.

Conservative force

A force is conservative if work done by the force on a particle that moves through any round trip (complete cycle) is zero, e.g. gravitational forces, electrostatic forces, elastic forces are conservative in nature.

Non-conservative force

A force is non-conservative if work done by the force on a particle that moves through any round trip (complete cycle) is not zero, e.g. frictional forces are non-conservative in nature.

2.2 Inertia

It is 'the natural tendency of an object to remain at rest or in motion at a constant speed along a straight line'. It is the tendency of an object to resist any attempt to change in its velocity.

- The mass of an object is a quantitative measure of inertia. More the mass, more will be the inertia of an object and vice-versa.

  Inertia of an object can be of three types :

  (1) **Inertia of rest**, the tendency of an object to remain at rest. This means an object at rest remains at rest unless a sufficiently large external force is applied on it.

  (2) **Inertia of motion**, the tendency of an object to remain in the state of uniform motion. This means an object in uniform motion remains continue to move uniformly unless an external force is applied on it.

  (3) **Inertia of direction**, the tendency of an object to maintain its direction. This means an object moving in a particular direction remains continue to move in that unless an external force is applied to change it.

- ### Newton's first law of motion (Galileo's law of inertia)

'Every object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it'.

2.3 Linear momentum (or momentum)

When someone asks you whether you would hit more by a piece of chalk or by a cork ball at first, the answer seems to be the cork ball. But if the chalk was moving at 250 m/s, then you're basically dealing with a bullet, and the choice becomes obvious.

- Momentum is an important concept when considering impacts, collisions, and how objects interact in general. It is not just an object's mass or an object's velocity that is important; it is the product of its mass and velocity.

The product of the mass (m) & velocity ($\vec{v}$) is called linear momentum.

$$\boxed{\vec{p} = m\vec{v}}$$

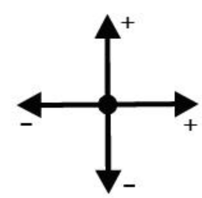


Fig.1 Sign convention for linear momentum

Linear momentum is a vector quantity. Its direction is 'the direction along the velocity'.

The linear momentum of a particle is directly proportional to (i) its mass (ii) its velocity.

Unit of linear momentum : SI unit : kg m/s or kg m s^{-1} or Newton-second (N-s)

C.G.S. unit : g cm/s or g cm s^{-1} or Dyne-second

- Linear momentum can be positive or negative depending on its direction.

For a given velocity, the momentum is directly proportional to the mass of the object ($p \propto m$). This means more the mass, more will be the momentum and vice-versa. If a car and a truck has same velocity, then, the momentum of truck is more than the momentum of car as the mass of a truck is greater than the mass of a car.

For a given mass, the momentum is directly proportional to the velocity of the object ($p \propto v$). This means more the velocity, more will be the momentum and vice-versa. If two bodies with same masses move with different velocities then, the body having more velocity will have more momentum.

For a given momentum, the velocity is inversely proportional to the mass of the object ($v \propto 1/m$). This means smaller the mass, more will be the velocity of an object and vice-versa. If a car and a truck has same momentum, the velocity of car will be more than the velocity of truck as the mass of a car is smaller than the mass of a truck.

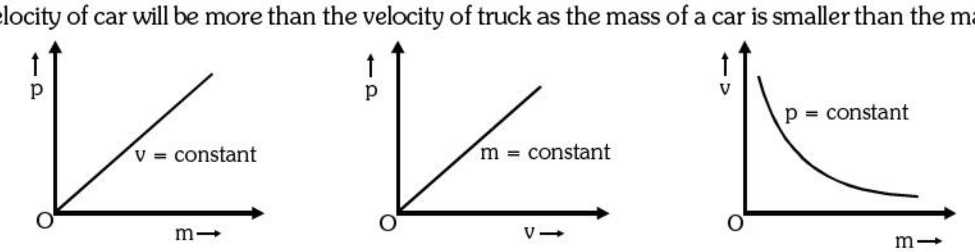


Fig.2 Different graphs related to momentum

- When a object is moving along a circular path, its velocity is tangential to the circular path hence, its momentum is also tangential to the circular path.

Momentum (p) of a photon

A photon is considered as massless, chargeless particle of an electromagnetic wave like visible light, X rays, ultraviolet rays, radio waves, etc. but it carries energy,

$$\boxed{p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}}$$

Where, E = energy carried by a photon = $h\nu$; h = Planck's constant = 6.63×10^{-34} J s ;
ν = frequency of electromagnetic wave ; λ = wavelength of electromagnetic wave.

2.4 Newton's second law of motion

'The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts'. Mathematically, it can be represented as,

$$\boxed{F = ma = \frac{p_2 - p_1}{t} = \frac{m(v-u)}{t}}.$$

- If force is constant i.e., F = ma = constant, then, the acceleration produced in the body is inversely proportional to its mass, i.e. $a \propto 1/m$. This means, if same force F is applied to masses m_1 and m_2 and the resulting accelerations in them are a_1 and a_2 respectively, then, $m_1a_1 = m_2a_2$

or $\boxed{\frac{a_2}{a_1} = \frac{m_1}{m_2}}$.

- 1 newton is the amount of force that produces an acceleration of 1 m s^{-2} in an object of 1 kg mass. Similarly, 1 dyne is the amount of force that produces an acceleration of 1 cm s^{-2} in an object of 1 g mass.

1 N = 10^5 dynes

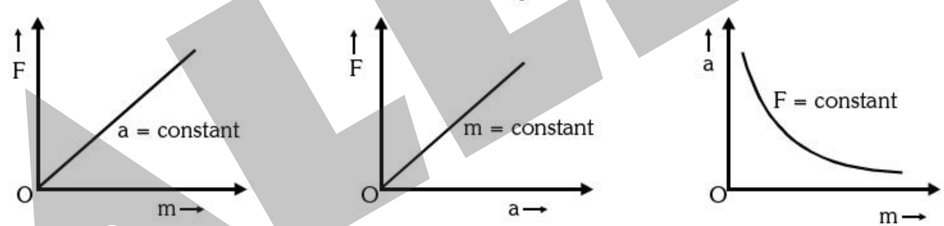


Fig.3 Graphs related to force, mass and acceleration

Impulse (J)

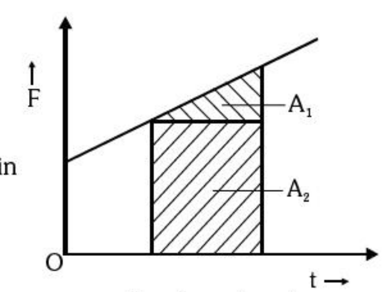
The product of force and time is called 'impulse'. It is also the change in momentum of the body. It is a vector quantity.

$$\boxed{J = F \times t = \Delta p = p_2 - p_1 = m(v-u)}$$

A large force acting for a short time that produces a significant change in momentum is called an **impulsive force**.

If force F acting is variable then, impulse, $\boxed{J = F_{av} \times t}$

- Area under the force-time graph gives impulse (see fig.4).



Impulse = $A_1 + A_2$

Fig.4 Area under F-t graph gives impulse

Newton's third law of motion

Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body'.

'**To every action, there is always an equal and opposite reaction**'.

Forces always exist in pairs : When two objects interact, two forces will always be involved. One force is the action force and the other is the reaction force.

- Consider a pair of bodies A and B. According to the Newton's third law, $\vec{F}_{AB} = -\vec{F}_{BA}$

  Where, F_{AB} = force on A due to B and F_{BA} = force on B due to A

  Though action-reaction pair are equal in magnitude and opposite in direction but the reaction force always acts on a different object than the action force. Thus, these forces do not cancel out each other. Hence, there can be an acceleration in an object.

  Newton's third law is applicable to non-contact forces also. For example, the Earth pulls an object downwards due to gravity. The object also exerts the same force on the Earth but in upward direction. But, we hardly see the effect of the stone on the Earth because the Earth is very massive and the effect of a small force on its motion is negligible. That is, the acceleration of Earth is negligible due to its huge mass.

- Even though the action and reaction forces are always equal in magnitude, these forces may not produce accelerations of equal magnitudes. This is because each force acts on a different object that may have a different masses.

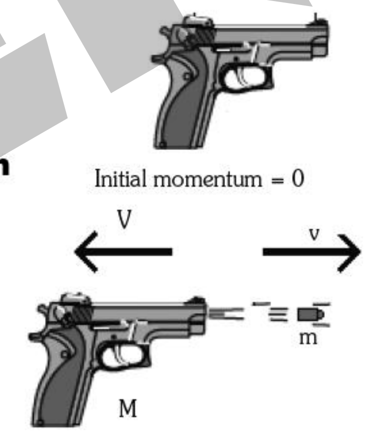
2.5 Conservation of linear momentum

'When the net external force on a system of objects is zero, the total linear momentum of the system remains constant'. In other words 'the total momentum of an isolated system of objects remains constant'.

The term '**collision**' is used to represent the event of two particles coming together for a short time and thereby producing 'impulsive forces' on each other. These forces are assumed to be much greater than any external forces present because they act for a very short time interval.

Momentum is conserved for all types of collisions that take place in real world in the absence of any external force.

- Rocket propulsion or the recoil of gun are based on law of conservation of momentum as well as Newton's third law. This is because the law of conservation of momentum is derived using Newton's third law.



Final momentum = mv – MV = 0

Fig.5 Recoil of a gun or pistol

Solving problems on conservation of momentum

- **Recoil of a gun :** Initial momentum = Final momentum

  or $0 = MV - mv$ or $\boxed{V = \frac{m}{M}v}$ (see fig.5)

- A bullet is fired on a wooden block and it gets embedded in it, after that they move together with a common velocity (see fig.6).

  Initial momentum = Final momentum

  or $mu = (M + m)V$ or $\boxed{V = \frac{mu}{M+m}}$

- A bomb of mass M explodes in two parts having masses m_1 and m_2 (see fig.7).

  Final momentum = initial momentum

  or $m_2v_2 - m_1v_1 = 0$ or $\mathbf{m_2v_2 = m_1v_1}$

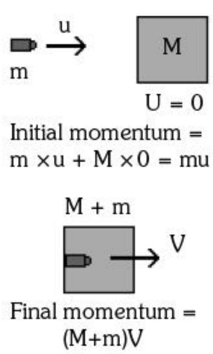


Fig.6

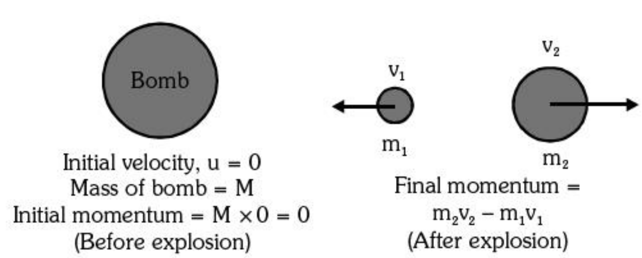


Fig.7

NUMERICAL CHALLENGE 2.1

A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12 m s^{-1}. If the mass of the ball is 0.15 kg, determine the change in momentum. Also, find the impulse imparted to the ball. (Assume linear motion of the ball).

Solution

Initial velocity, $u = +12$ m s^{-1} ; final velocity, $v = -12$ m s^{-1} ; mass, $m = 0.15$ kg

Change in momentum = $mv - mu = m(v - u)$

$= 0.15 \times [(-12) - (+12)] = 0.15 \times -24$

$= \mathbf{-3.6\ kg\ m\ s^{-1}}$

Impulse = change in momentum = $\mathbf{-3.6\ kg\ m\ s^{-1}}$

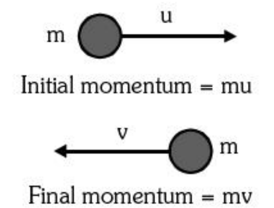


Fig.8 Numerical challenge 2.1

NUMERICAL CHALLENGE 2.2

A body of mass 1 kg moving with a speed of 50 m/s hits a wall and rebounds with the same speed. If the contact time is (1/25) s, find the force applied on the wall.

Solution

Given, mass of the body, $m = 1$ kg ; initial velocity of the body, $u = +50$ m/s ;
final velocity of the body, $v = -50$ m/s ; contact time, $t = (1/25)$ s

Initial momentum of the body, $p_1 = mu = 1 \times (+50) = +50$ kgm/s

Final momentum of the body, $p_2 = mu = 1 \times (-50) = -50$ kgm/s

Change of momentum of the body, $\Delta p = p_2 - p_1 = (-50) - (+50) = -100$ kgm/s

Force applied on the body, $F = \dfrac{\Delta p}{t} = \dfrac{-100}{(1/25)} = -2500$ N

Force applied on the wall = – Force applied on the body (Action-reaction pair)

$= -(-2500\text{ N}) = \mathbf{+2500\ N}$

NUMERICAL CHALLENGE 2.3

A bullet of mass 0.04 kg moving with a speed of 90 m s^{-1} enters a heavy wooden block and is stopped after a distance of 60 cm. What is the average resistive force exerted by the block on the bullet ?

Solution

Mass of bullet, $m = 0.04$ kg ; initial speed, $u = 90$ ms^{-1} ; final speed, $v = 0$;
distance, $s = 60$ cm $= (60/100)$ m $= 0.6$ m

From third equation of motion, $v^2 = u^2 + 2as$ or $(0)^2 = (90)^2 + 2a(0.6)$

or $a = -\dfrac{(90)^2}{2 \times 0.6} = -6750$ ms^{-2}

$\therefore$ Force, $F = ma = (0.04)(-6750) = \mathbf{-270\ N}$

NUMERICAL CHALLENGE 2.4

A shell of mass 0.020 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m/s, what is the recoil speed of the gun ?

Solution

Given, mass of bullet, $m_1 = 0.020$ kg ; muzzle speed (speed of bullet), $v_1 = 80$ m/s ;
mass of gun, $m_2 = 100$ kg ; recoil speed, $v_2 = ?$

Initial momentum, $p_1 = 0$

Final momentum, $p_2 = m_1v_1 - m_2v_2$

By conservation of momentum,

Final momentum = Initial momentum

or $p_2 = p_1$

or $m_1v_1 - m_2v_2 = 0$

or $(0.020)(80) - (100)(v_2) = 0$ or $1.6 - 100v_2 = 0$

or $v_2 = (1.6/100)$ m/s $= \mathbf{1.6 \times 10^{-2}\ m/s}$

2.6 Tension in strings

Strings are assumed to be inextensible i.e., they cannot be stretched. Due to this assumption 'acceleration of masses connected through a string is always same. They are assumed to be massless unless it is mentioned. Due to this assumption 'tension in the string is same every where'.

If the string has mass, tension at different points will be different. It is maximum at the end at which force is applied and minimum at the other end connected to a mass.

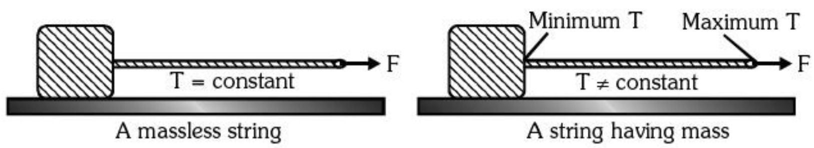


Fig.9 Tensions in the string

- The direction of tension at body (or a point) is always outward along the string i.e., away from the body along the string. A tension always has pulling action.

Free body diagrams

A system diagram is a sketch of all the objects involved in a situation. A free-body diagram (FBD) is a drawing in which only the object being analyzed is drawn, with arrows showing all the forces acting on the object.

(1) Free body diagrams represent all forces acting on one object.

(2) Forces that the object exerts on other objects do not appear in free body diagrams because they have no effect on the motion of the object itself.

(3) In drawing a free body diagram, you can represent the object as a single dot or a simplified shape the object.

(4) In FBD each force acting on the object is represented with an arrow. The arrow's direction shows the direction of the force and the arrow's relative length provides information about the magnitude of the force.

(5) Forces that have the same magnitude should be sketched with approximately the same length, forces that are larger should be longer, and smaller forces should be shorter.

(6) In case of objects in motion, the direction of acceleration should be made on the FBD in the direction of greater force (or net force).

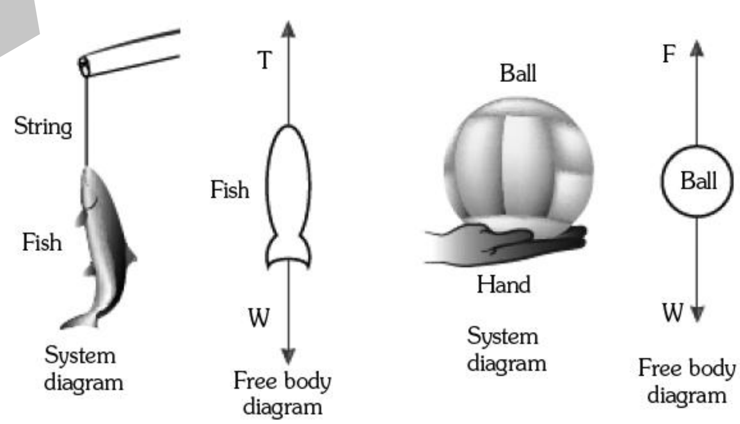


Fig.10 Making free body diagrams

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Motion of bodies connected by strings

Let us consider two bodies m_1 and m_2 placed on horizontal frictionless plane connected by a massless string. Let the mass m_1 is pulled by a force F. As a result the whole system moves in the direction of applied force with an acceleration a. Let the tension in the string be T (see fig.11).

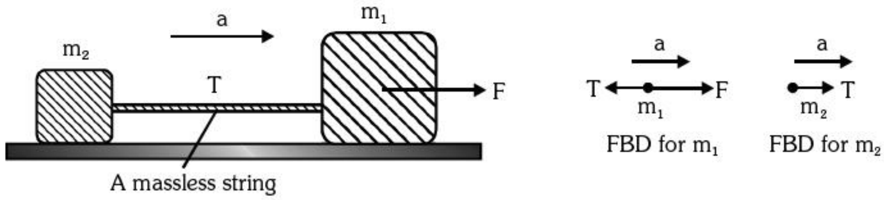


Fig.11 Motion of bodies connected by strings

For mass m_1, $F - T = m_1 a$ ----- (1) [F is greater force as it is in the direction of acceleration a]

For mass m_2, $T = m_2 a$ ----- (2) [Here, T is the only force acting on m_2]

(1) + (2) $\Rightarrow$ $(F - T) + T = m_1 a + m_2 a$

or $F = (m_1 + m_2)a$ or $\boxed{a = \dfrac{F}{m_1 + m_2}}$ From (2), we have, $T = m_2 a$ $\therefore$ $\boxed{T = \dfrac{m_2 F}{m_1 + m_2}}$

Motion of bodies connected by string passing over a light pulley (Atwood's Machine)

Let us consider two masses m_1 and m_2 passing over a light pulley connected through a string (see fig.12). The term 'light pulley' means the mass of pulley is neglected, it is assumed to be massless. Since the two bodies are connected with each other, both move with same acceleration a. Let $m_2 > m_1$ then, m_2 will go downwards while m_1 will go upwards.

For m_1, $T - m_1 g = m_1 a$ ----- (1)

[Here, $T > m_1 g$, as T is in the direction of acceleration a]

For m_2, $m_2 g - T = m_2 a$ ----- (2)

[Here, $m_2 g > T$, as $m_2 g$ is in the direction of acceleration a]

(1) + (2) $\Rightarrow$ $(T - m_1 g) + (m_2 g - T) = m_1 a + m_2 a$

or $(m_2 - m_1)g = (m_2 + m_1)a$

or $\boxed{a = \dfrac{(m_2 - m_1)g}{(m_2 + m_1)}}$

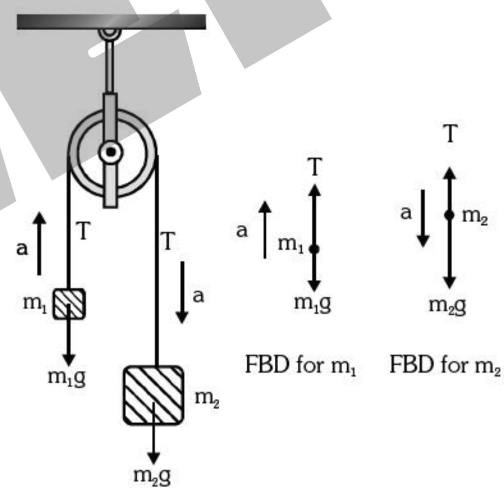


Fig.12 Motion of masses connected by a pulley

(Since $a \neq g$, two bodies are not free falling bodies.)

Putting the value of a in eq.(1), we get, $\boxed{T = \dfrac{2m_1 m_2 g}{m_1 + m_2}}$

Motion of bodies in contact

Let two bodies of masses m_1 and m_2 respectively are placed side by side touching each other. A push force 'F' is applied on m_1 such that both the bodies start moving together with an acceleration 'a'. Since both the bodies are touching each other there is a pair of action reaction force between them at place of their contact. These forces are called normal contact forces (see fig.13) and obviously they are equal in magnitude but opposite in direction (Newton's third law).

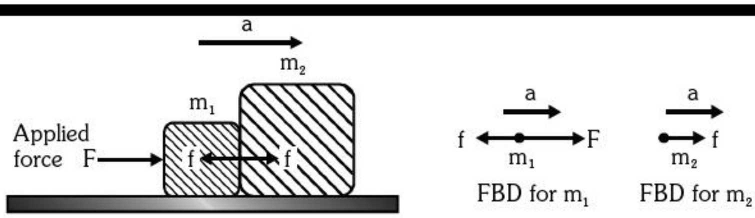


Fig.13 Motion of bodies in contact

For mass m_1, $F - f = m_1 a$ ---- (1) [F is greater force as it is in the direction of acceleration a]

For mass m_2, $f = m_2 a$ ----- (2) [Here, f is the only force acting on m_2]

$(1) + (2) \Rightarrow (F - f) + f = m_1a + m_2a$

or $F = (m_1 + m_2)a$ or $\boxed{a = \dfrac{F}{m_1 + m_2}}$ From (2), we have, $f = m_2a$ $\therefore$ $\boxed{f = \dfrac{m_2F}{m_1 + m_2}}$

■ Weight of an object in a lift

A weighing machine measures the normal force not the 'true weight'. Thus, if the normal force changes, the weighing machine does not give reading of true weight, it gives a reading of normal force which we can be called '**apparent weight**' of the object.

Let us consider a girl standing in a lift.

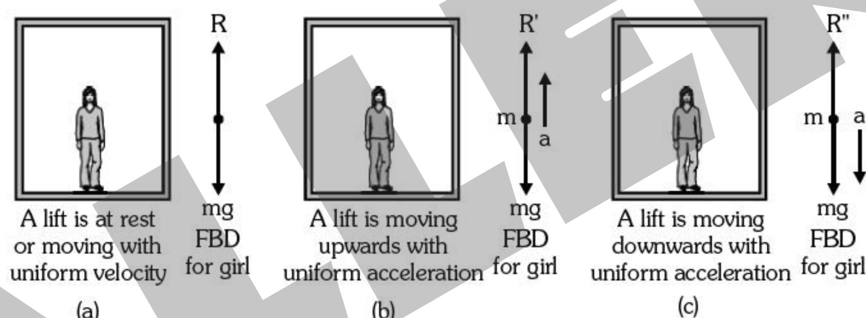


Fig.14 Weight of an object in a lift

(1) When the lift is at rest or in uniform motion, net acceleration of the system is zero [see fig.14(a)]. Thus, net force on it is zero.

$\therefore$ Net force, $F_{net} = mg - R = 0$ or $R = mg$

The R represents the apparent weight, i.e., **W = R = mg** [Apparent weight = true weight]

(2) When the lift is moving up with uniform acceleration a [see fig.14(b)]. Thus, net force on it is not zero.

$\therefore$ Net force, $F_{net} = R' - mg = ma$ [R' is greater force as it is in the direction of acceleration a]

or $R' = ma + mg = m(a + g)$

The R' represents the apparent weight, i.e., **W' = R' = m(a + g)** [Apparent weight > true weight]

(3) When the lift is moving down with uniform acceleration a [see fig.14(c)]. Thus, net force on it is not zero.

$\therefore$ $mg - R'' = ma$ [mg is greater force as it is in the direction of acceleration a]

or $R'' = mg - ma = m(g - a)$

The R" represents the apparent weight, i.e., **W" = R" = m(g – a)** [Apparent weight < true weight]

Suppose the rope of the lift breaks, then it will fall freely under gravity i.e., a = g. In this situation, apparent weight, $W'' = R'' = m(g - g) = 0$. That is, the weighing machine will read zero weight.

2.7 Friction

It is a force that opposes the relative movement between two surfaces in contact. Some important points related to friction are :

(1) The magnitude of the friction force depends on the types of surfaces in contact. The frictional force is usually larger on the rough surfaces and smaller on the smooth surfaces. Friction depends on both the surfaces that are in contact, therefore, the value of friction is different for different pairs of surfaces.

(2) Friction is always parallel to the surface in contact.

(3) If an object is allowed to move on a surface then, more the distance travelled by the object on the surface, less will be the friction between them and vice-versa.

(4) Friction is caused by the irregularities on the two surfaces in contact.

(5) There are many kinds of friction that exist in different media :

 (i) **Static friction :** It exists when two surfaces try to move across each other but not enough force is applied to cause motion.

 (ii) **Sliding friction :** It exists when two surfaces slide across each other.

 (iii) **Rolling friction :** It exists when one object rolls over another object.

 (iv) **Air friction (air resistance) :** It exists when an object moves through air.

 (v) **Viscous friction :** It exists when objects move through water or other liquids.

(6) Force of friction increases if the two surfaces are pressed harder. The greater the force pressing the two surfaces together, the greater will be the force of friction between them.

(7) Friction increases with weight. For a heavy object, the weight is quite large, therefore, the push force (pressing force) between the object and the floor is also large. Thus, the friction force between them is large.

(8) For hard contact surfaces, the force of friction does not depend on the 'area of contact' between the two surfaces. But, it is not true if the surfaces are wet, or if they are soft. Rubber is soft as compared to the surface of a road. The friction between rubber and surface of road also depends on how much rubber is contacting with the surface of road. Thus, wide tires (made of rubber) have more friction than narrow tires.

Static friction

It is the force exerted on an object at rest that prevents the object from sliding.

- The direction of static friction is opposite to the applied force. Also, it acts in a direction opposite to the direction in which an object tends to move.
- The maximum value of static friction is called the **starting friction** or **limiting friction**. It is the amount of force that must be overcome to start a stationary object moving.

The law of static friction may be written as, $\boxed{f_s \le \mu_s N}$

Where, μ_s = coefficient of static friction, depends only on the nature of surfaces in contact ;
 N = normal force (or normal reaction).

Limiting (maximum) value of static friction is given by, $\mathbf{f_L = \mu_s N}$. If the applied force F exceeds f_L , the body begins to slide on the surface.

- If applied force F is less than f_L, then, $\mathbf{F = f_s}$ i.e., applied force is equal to the value of static friction and body will remain at rest.

Sliding friction (or kinetic friction)

It is the force exerted on an object in motion that opposes the motion of the object as it slides on another object.

- Sliding or kinetic friction is smaller than the limiting value of static friction. This is because it takes more force to break the interlocking between two surfaces than it does to keep them sliding once they are already moving.
- Kinetic friction, like static friction, is also found to be independent of the area of contact. Further, it is nearly independent of the velocity of the body.

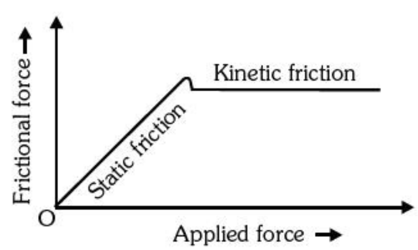
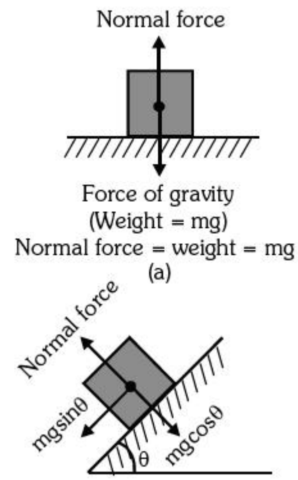


Fig.15 Variation of friction with applied force

The law of kinetic friction may be written as, $\boxed{f_k = \mu_k N}$



Normal force = mgcosθ
(b)
Fig.16 Normal forces on horizontal and inclined plane

Where μ_k is the coefficient of kinetic friction, depends only on the nature of surfaces in contact.

$\boxed{\mu_s > \mu_k}$, μ_s and μ_k have no units as they are ratio of two forces.

- Normal force on a horizontal plane is, N = mg while normal force on an inclined plane is mgcosθ, where 'θ' is the angle made by the plane with the horizontal.
- Note that it is not motion, but relative motion that the frictional force opposes.

Angle of repose (θ)

If a body is placed on an inclined plane and if its angle of inclination is gradually increased, then at some angle of inclination θ the body will start just sliding down. This angle of the inclined plane at which the body just starts sliding is called angle of repose (θ).

From fig., we have, f_L = mgsinθ ----- (1)

R = mgcosθ ----- (2)

$$\frac{(1)}{(2)} \Rightarrow \frac{f_L}{R} = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta$$

or $\boxed{\tan\theta = \mu_s}$

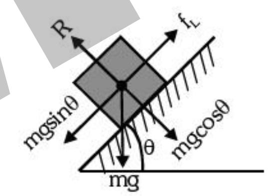


Fig.17 Angle of repose

(1) If angle of inclination (α) of the plane is less than angle of repose (θ), the body will remain at rest.

(2) If α = θ, then body will just slide i.e., will move uniformly. (see fig.17)

(3) If α > θ, the body will accelerate downwards. The acceleration can be found by the fig.18.

$F_{net} = mg\sin\alpha - f_k = mg\sin\alpha - \mu_k R = mg\sin\alpha - \mu_k mg\cos\alpha$

or $ma = m(g\sin\alpha - \mu_k g\cos\alpha)$

or $\mathbf{a = g(\sin\alpha - \mu_k\cos\alpha)}$

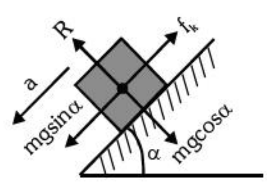


Fig.18

- If there is no friction, acceleration on the inclined plane, a = gsinα, where α is the angle made by the inclined plane with the horizontal.

Rolling friction

The rolling motion of the wheel is a combination of both spin (rotational) motion and linear (translational) motion.

When one body rolls over the surface of another body, the resistance (opposition) to its motion is called the **rolling friction**.

- Rolling reduces the friction significantly. Since the rolling friction is smaller than the sliding friction, sliding is replaced in most machines by rolling by the use of ball bearings.
- Rolling friction increases with the deformation of tyre or wheel. Thus, rolling friction of a tyre or wheel made of rubber is more than a tyre or wheel made of iron. This is because the iron wheel deforms negligibly while rubber tyre deforms significantly.

EXERCISE

Multiple choice questions

1. When balanced forces act on a body, the body

(1) must remain in its state of rest

(2) must continue moving with uniform velocity, if already in motion

(3) must experience some acceleration

(4) both (1) and (2)

2. Which of the following physical quantities will have different unit as compared to that of others?

(1) Weight of a body (2) Tension in the string

(3) Buoyant force (4) Electromotive force

3. An object of mass 20 g is executing uniform circular motion on a circular path of radius 2 m with a time period of 1/2 sec. Find centripetal force acting on it.

(1) 4.32 N (2) 5.32 N (3) 6.32 N (4) 7.32 N

4. An electron in the hydrogen atom is making 6×10^{15} revolutions per second. Calculate the centripetal force if the radius of circular orbit is 0.53 Å. (mass of an electron = 9.1×10^{-31} kg)

(1) 5.8×10^{-8} N (2) 6.8×10^{-8} N (3) 7.8×10^{-8} N (4) 8.8×10^{-8} N

5. An object of mass 5 kg is rotated in a horizontal plane by means of a string of length 2 m. Find the centripetal force if the object is rotated with a constant speed of 3 ms^{-1}.

(1) 12.5 N (2) 20.5 N (3) 22.5 N (4) 32.5 N

6. A stone weighing 250 g is tied to a string of length 25 cm and whirled in a horizontal plane over the top of a frictionless table with a uniform speed. Find the maximum speed with which the stone can be whirled if the string can bear at most a load of 14.4 kgf. (take g = 10 ms^{-2})

(1) 10 ms^{-1} (2) 11 ms^{-1} (3) 12 ms^{-1} (4) 13 ms^{-1}

7. A body of mass 500 gm revolves in a horizontal circle of radius 1 m at a speed 5 ms^{-1}. Calculate the centripetal force acting on the body.

(1) 10 N (2) 12.5 N (3) 15 N (4) 17.5 N

8. A particle of mass 'm' is executing uniform circular motion on a circular path of radius 'r' due to a continuous action of centripetal force F. Calculate its period of rotation.

(1) $T = 2\pi\sqrt{\frac{F}{mr}}$ (2) $T = 2\pi\sqrt{\frac{mr}{F}}$ (3) $T = 2\pi\sqrt{\frac{r}{mF}}$ (4) $T = \frac{1}{2\pi}\sqrt{\frac{mr}{F}}$

9. An electron revolves around the nucleus in circular orbit. The necessary centripetal force develops from

(1) Nuclear force (2) Electrostatic repulsive force

(3) Electrostatic attraction force (4) Gravitational force

10. A satellite orbiting in a circular orbit acquires the necessary centripetal force from

(1) Electrostatic force (2) Gravitational force (3) Nuclear force (4) Magnetic force

11. A constant force F acts on a stationary body for time t. The distance covered by the body 'S' will be proportional to

(1) t (2) $\frac{1}{t}$ (3) t^2 (4) $\frac{1}{t^2}$

12. A batsman hits a cricket ball, which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows down to stop because

(1) the batsman did not hit the ball hard

(2) velocity of ball is proportional to force acting on it

(3) there is a force on the ball opposing its motion

(4) there is no unbalanced force on the ball and hence it comes to rest

13. An 8000 kg engine pulls a train of 5 wagons, each of 2000 kg along a horizontal track. If the engine exerts a force of 40,000 N and track offers a friction of 5000 N, then net accelerating force acting on the system is

(1) 45,000 N (2) 40,000 N (3) 35,000 N (4) none of the above

14. A bullet of mass 25 g and velocity 50 ms^{-1} passes through a board 7.5 cm thick and emerges with a velocity of 40 ms^{-1}. What is the average force exerted by the board on the bullet?

(1) 150 N (2) 15 N (3) 1.5 N (4) 0.15 N

15. What happens to the inertia of an object when its velocity is doubled?

(1) The object's inertia becomes $\sqrt{2}$ times greater.

(2) The object's inertia becomes 2 times greater.

(3) The object's inertia becomes 4 times greater.

(4) The object's inertia is unchanged.

16. A particle is in straight line motion with uniform velocity. A force is not required

(1) To increase the speed (2) To decrease the speed

(3) To keep the same speed (4) To change the direction

17. The tendency of a body to continue in its state of rest or uniform motion, in the absence of external force, is called

(1) force (2) momentum (3) inertia (4) impulse

18. Essential characteristic of equilibrium is

(1) Momentum equals zero (2) Acceleration equals zero

(3) K.E. equals zero (4) Velocity equals zero

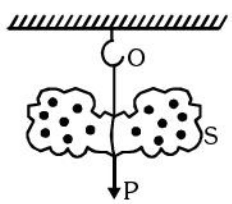
19. A stone is tied to the middle of a string and suspended from one end as shown in the fig. Here S is the stone and O is the point of suspension. If you give a sharp jerk at P, the string will break

(1) Below the stone

(2) At the point P itself

(3) From above the stone

(4) Nothing can be decided



20. In the above problem, if we increase the pull at P gradually, the string will break

(1) Below the stone (2) At the point P itself (3) Above the stone (4) Nothing can be decided

21. A water tanker filled up to $(2/3)^{rd}$ of its height is moving with a uniform speed. On sudden application of the brake, the water in the tank would

(1) move backward (2) move forward (3) be unaffected (4) rise backward

22. A truck starts from rest and rolls down the hill with a constant acceleration. It travels 400 m in 20 s. If the mass of truck is 7 metric tonnes, the force acting on it is

(1) 28,000 N (2) 14,000 N (3) 1400 N (4) 24,000 N

23. A particle of mass 0.3 kg is subjected to force F = kx with k = 15 N/m and x being its distance from the origin. What will be its intial acceleration if it is released from a point 20 cm away from the origin?

(1) 5 m/s^2 (2) 10 m/s^2 (3) 3 m/s^2 (4) 15 m/s^2

24. A body of mass 'm' kg starts from rest and travels a distance of 's' m in 't' seconds. The force acting on it is

(1) $\frac{2ms}{t^2}N$ (2) $\frac{ms}{t}N$ (3) $\frac{ms^2}{2t}N$ (4) $\frac{ms^2}{t}N$

25. When a constant force acts on a mass 'm' which is at rest initially, the velocity acquired in a given displacement is proportional to

(1) $\sqrt{m}$ (2) $\frac{1}{\sqrt{m}}$ (3) m (4) $\frac{1}{m}$

26. A cricket ball of mass 150 grams is moving with a velocity of 12 m/sec and is hit by a bat so that the ball is turned back with a velocity of 20 m/s. The force of the blow acts on the ball for 0.01 sec. The average force exerted on the ball by the bat in Newtons is

(1) 120 N (2) 240 N (3) 480 N (4) 960 N

27. A cricket ball of mass 0.16 kg, travelling at 25 m/s is intercepted by a player who fields it cleanly in 0.2 s. The force exerted on his hands is

(1) 20 N (2) 25 N (3) 30 N (4) 40 N

28. A ball is dropped on the floor from a height of 10 m. It rebounds to a height of 2.5 m. If the ball is in contact with the floor for 0.01 sec, then average acceleration during contact is

(1) 2100 m/s^2 (2) 1400 m/s^2 (3) 700 m/s^2 (4) 400 m/s^2

29. The mass of an aeroplane is 2.5 tonnes. Its engine develops a force of 8750 N before taking off. The acceleration of the aeroplane at the time of take off is

(1) 3.45 ms^{-2} (2) 3.65 ms^{-2} (3) 3.50 ms^{-2} (4) 3.60 ms^{-2}

30. A hammer weighing 3 kg, moving with a velocity of 10 m/s, strikes against the head of a spike and drives it into a block of wood. The hammer comes to rest in 0.025 s. The impulse associated with the hammer will be

(1) 30 Ns (2) –30 Ns (3) 15 Ns (4) –15 Ns

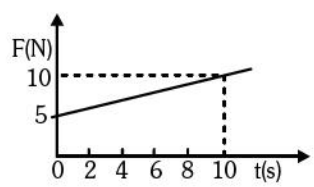
31. A varying force of F Newtons acts on a body of mass 10 kg. The relation between F & t is shown by the graph in fig. What is the change in speed of the object between t = 0 s & t = 10 s?

(1) 7.5 ms^{-1}

(2) 5.0 ms^{-1}

(3) 12.5 ms^{-1}

(4) 15.0 ms^{-1}



32. A body P has mass 2 m and velocity 5 v. Another body Q has mass 8 m and velocity 1.25 v. The ratio of momentum of P and Q is

(1) 2 : 1 (2) 1 : 1 (3) 1 : 2 (4) 3 : 2

33. Action-reaction forces

(1) act on same body (2) act on different bodies

(3) act along different lines (4) act in same direction

34. A cracker at rest explodes into two equal parts. These parts will move in

(1) opposite direction with different speeds (2) same direction with different speeds

(3) same direction with same speeds (4) opposite direction with same speeds

35. A batsman has a choice to use heavy or light bat, while facing a fast bowler. He will prefer

(1) light bat, because handling it is easy (2) heavy bat, so that he can handle it firmly

(3) heavy bat, because it will recoil less (4) none of the above

36. A rocket works on the principle of

(1) conservation of energy (2) conservation of linear momentum

(3) conservation of inertia (4) conservation of force

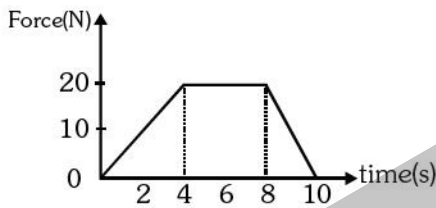
37. A body of mass 5 kg is acted on by a net force which varies as shown by the graph. The change in momentum obtained would be

(1) 10 Ns

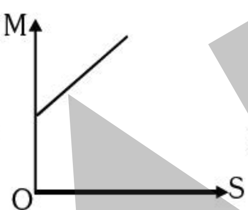
(2) 100 Ns

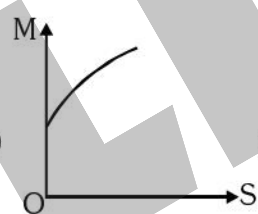
(3) 140 Ns

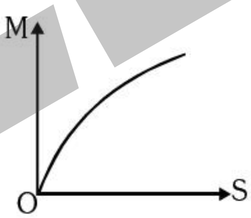
(4) 200 Ns

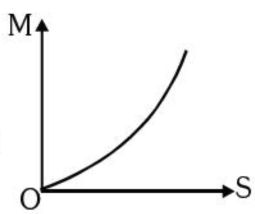


38. A toy train starts from rest and is driven along a horizontal track by a motor which exerts a constant driving force. The effects of friction and air resistance can be neglected. Which of the following graphs best represents the momentum (M) of train as a function of distance (S)?

(1)


(2)


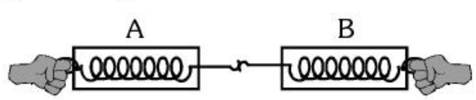
(3)


(4)


39. Two identical bodies are allowed to fall from different heights h_1 & h_2. The ratio of their momentum when they reach the ground will be

(1) $h_1 : h_2$ (2) $h_1^2 : h_2^2$ (3) $\sqrt{h_1} : \sqrt{h_2}$ (4) 1

40. Consider two spring balances hooked as shown in the figure. We pull them in opposite directions. If the reading shown by A is 1.5 N, the reading shown by B will be



(1) 1.5 N (2) 2.5 N (3) 3.0 N (4) Zero

41. A missile of mass M moving with velocity v in free space explodes into two parts. After the explosion one of the parts of mass m falls vertically down. The other part proceeds with velocity

(1) $\frac{Mv}{m}$ (2) $\frac{Mv}{(M-m)}$ (3) $\frac{(M-m)v}{M}$ (4) $\frac{mv}{M-m}$

42. A 30 g bullet is fired horizontally with velocity 250 m/s, from a 1.5 kg gun. If the gun is held loosely in hand, its recoil velocity would be

(1) 5 m/s (2) 4 m/s (3) 3 m/s (4) 2 m/s

43. A body of mass m collides against a wall with a velocity v and rebounds with the same speed. The change in its momentum is

(1) zero (2) –2 mv (3) mv (4) –mv

44. The principle of conservation of linear momentum states that in a system it

(1) cannot be changed (2) can be changed, if internal forces act on it

(3) can be changed, if external forces act on it (4) none of the above

45. A porter is carrying a weight of 200 N on his head. If the force exerted on his head is taken as action, then the reaction force is exerted by

(1) the head on the weight (2) the weight on the earth

(3) the earth on the porter (4) the earth on the weight

46. A body is moving with a constant momentum. The motion of the body is

(1) uniform velocity (2) accelerated (3) decelerated (4) none of the above

47. An electron of mass 9×10^{-31} kg is moving in a straight line path with a velocity of 6×10^{7} ms^{-1}. The momentum of electron is

(1) 5.4×10^{-23} Ns (2) 5.4×10^{-24} Ns (3) 4.5×10^{-23} Ns (4) 0.5×10^{-24} Ns

48. From a rifle of mass 4 kg, a bullet of mass 50 g is fired with a speed of 35 ms^{-1}. Calculate the recoil speed of the rifle.

(1) 0.7375 ms^{-1} (2) 0.6375 ms^{-1} (3) 0.4375 ms^{-1} (4) 0.5375 ms^{-1}

49. An object A of mass 2 kg is moving with a velocity of 3 m/s and collides head-on with an object B of mass 1 kg moving in opposite direction with a velocity of 4 m/s. After collision, both objects coalesce so that they move with a common velocity equal to

(1) 3 m/s (2) 2 m/s (3) 1 m/s (4) 2/3 m/s

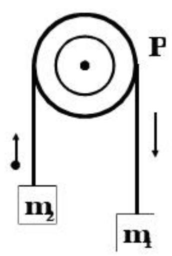
50. Two objects of masses 100 g and 200 g are moving along the same line and direction, with velocities 2 ms^{-1} and 1 ms^{-1}, respectively. They collide and after the collision, the second object moves with a velocity of 1.67 ms^{-1}. Determine the velocity of the first object.

(1) 0.66 ms^{-1} (2) 1.66 ms^{-1} (3) 2.66 ms^{-1} (4) 3.66 ms^{-1}

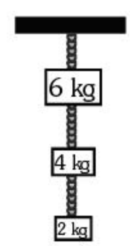
51. In the following pulley system, the tension in the string will be

(1) $\left(\frac{m_1 - m_2}{m_1 + m_2}\right)g$ (2) $\left(\frac{2m_1m_2}{m_1 + m_2}\right)g$

(3) $\left(\frac{m_1 + m_2}{m_1 - m_2}\right)g$ (4) $\left(\frac{4m_1m_2}{m_1 + m_2}\right)g$



52. Three masses of 6 kg, 4 kg and 2 kg are attached to a rigid support as shown in figure. If the string attached to the support breaks and the system falls freely, then the tension in the string connecting 4 kg and 2 kg mass is



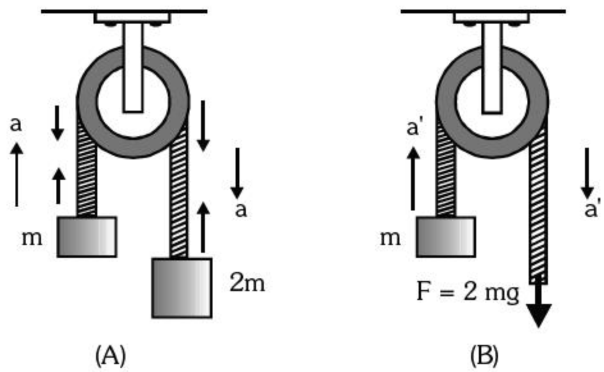
(1) zero

(2) 8 kg wt

(3) 12 kg wt

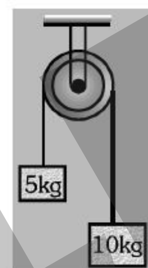
(4) 6 kg wt

53. The pulley arrangements of Fig. (A) and (B) are identical. The mass of the ropes is negligible. In (A), the mass m is lifted up by attaching a mass 2m to the other end of the rope. In (B), m is lifted up by pulling the other end of the rope with a constant downward force F = 2 mg. In which case the acceleration of 'm' is more?



(1) B (2) A (3) Equal in both (4) Cannot be found

54. Two masses of 5 kg and 10 kg are connected to a pulley as shown. What will be the acceleration if the pulley is set free? (g = acceleration due to gravity)



(1) g

(2) $\frac{g}{2}$

(3) $\frac{g}{3}$

(4) $\frac{g}{4}$

55. Three solids of mass m_1, m_2 and m_3 are connected with weightless string in succession and are placed on a frictionless table. If the mass m_3 is dragged with a force T, the tension in the string between m_2 and m_3 is

(1) $\frac{m_2}{m_1+m_2+m_3}T$ (2) $\frac{m_3}{m_1+m_2+m_3}T$ (3) $\frac{m_1+m_2}{m_1+m_2+m_3}T$ (4) $\frac{m_2+m_3}{m_1+m_2+m_3}T$

56. Two particles of masses m and M (M > m) are connected by a cord that passes over a massless, frictionless pulley. The tension T in the string and the acceleration a of the masses is

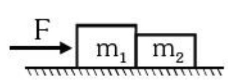
(1) $T=\left(\frac{2mM}{M-m}\right)g; a=\left(\frac{Mm}{M+m}\right)g$ (2) $T=\left(\frac{2mM}{M+m}\right)g; a=\left(\frac{M-m}{M+m}\right)g$

(3) $T=\left(\frac{M-m}{M+m}\right)g; a=\left(\frac{2mM}{M+m}\right)g$ (4) $T=\left(\frac{Mm}{M+m}\right)g; a=\left(\frac{2mM}{M+m}\right)g$

57. Two masses of 3 kg and 4 kg are suspended over a frictionless pulley by a string joining them. The acceleration of the system will be

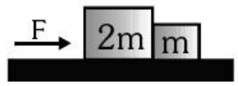
(1) 4.9 m/s^2 (2) 2.45 m/s^2 (3) 1.4 m/s^2 (4) 9.8 m/s^2

58. In the system shown below, a constant force F is applied. The reaction offered by m_2 upon m_1 is



(1) $\frac{m_1F}{m_1+m_2}$ (2) $\frac{m_2F}{m_1+m_2}$ (3) $\left(\frac{m_1-m_2}{m_2}\right)F$ (4) zero

59. Two blocks are in contact on a frictionless table. One has mass m and the other 2m. A force F is applied on 2 m as shown in figure. Now the same force F is applied from the right on m. In the two cases the ratio of force of contact between the two blocks will be



(1) 1 : 1 (2) 1 : 2 (3) 2 : 1 (4) 1 : 3

60. The force exerted by the floor of an elevator on the feet of a person standing there is more than the weight of the person, if the elevator is

(1) Going up and slowing down
(2) Going down and slowing down
(3) Going up and speeding up
(4) Both (2) and (3)

61. A boy of mass 50 kg is standing on a weighing machine placed on the floor of a lift. The machine reads his weight in N. What is the reading of the machine if the lift is moving upwards with a uniform speed of 10 m s^{-1}?

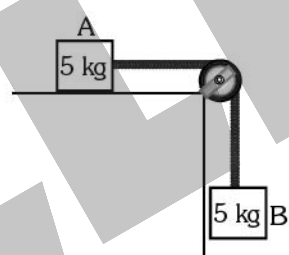
(Take g = 10 m s^{-2})

(1) 510 N (2) 480 N (3) 490 N (4) 500 N

62. A lift is descending with an acceleration 2 m/sec^2. What will be the apparent weight of a person of 80 kg mass?

(1) 640 N (2) 72 N (3) 48 N (4) 480 N

63. A block of mass 5 kg resting on a horizontal surface is connected by a cord, passing over a light frictionless pulley to a hanging block of mass 5 kg. The coefficient of kinetic friction between the block and the surface is 0.5. Tension in the cord is (g = 9.8 m/s^2)



(1) 49 N (2) zero (3) 36.75 N (4) 12.75 N

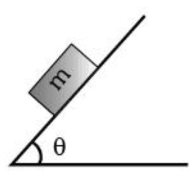
64. A 30 kg block rests on a rough horizontal surface. A force of 200 N is applied on the block. The block acquires a speed of 4 m/s, starting from rest, in 2 s. What is the value of coefficient of friction?

(1) $\frac{10}{3}$ (2) $\frac{\sqrt{3}}{10}$ (3) 0.47 (4) 0.185

65. A block of mass 0.1 kg is held against a wall applying a horizontal force of 5 N on the block. If the coefficient of friction between the block and the wall is 0.5, the magnitude of the frictional force acting on the block is

(1) 2.5 N (2) 0.98 N (3) 4.9 N (4) 0.49 N

66. A block of mass m is at rest on an inclined plane which is making angle θ with the horizontal. The coefficient of friction between the block and plane is μ. Then, frictional force acting between the surfaces is



(1) μmg
(2) μmg sin θ
(3) μ (mg sin θ – mg cos θ)
(4) mg sin θ

67. A balloon of weight w is falling vertically downward with a constant acceleration a $(< g)$. The magnitude of the air resistance is

(1) w (2) $w\left(1+\frac{a}{g}\right)$ (3) $w\left(1-\frac{a}{g}\right)$ (4) $w\frac{a}{g}$

68. Assertion : Action-reaction forces act on two different objects.

Reason : Action and reaction have zero resultant.

(1) Both assertion and reason are correct and reason is the correct explanation of assertion.
(2) Both assertion and reason are true but reason is not the correct explanation of assertion.
(3) Assertion is true but reason is false.
(4) Assertion is false but reason is true.

69. Assertion : When brakes are applied on a wet road, a car is likely to skid.

Reason : Brakes prevent rotation of the wheels and there is not sufficient friction between the road and the wheels to stop the translational motion.

(1) Both assertion and reason are correct and reason is the correct explanation of assertion.
(2) Both assertion and reason are true but reason is not the correct explanation of assertion.
(3) Assertion is true but reason is false.
(4) Assertion is false but reason is true.

70. Assertion : The slope of momentum versus time curve gives us the acceleration.

Reason : Acceleration is given by the rate of change of momentum.

(1) Both assertion and reason are correct and reason is the correct explanation of assertion.
(2) Both assertion and reason are true but reason is not the correct explanation of assertion.
(3) Assertion is true but reason is false.
(4) Assertion is false but reason is true.
(5) Both assertion and reason are false.

ANSWERS

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	4	4	3	2	3	3	2	2	3	2	3	3	3	1	4	3	3	2	1	3
Que.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	2	2	2	1	2	3	1	1	3	2	1	2	2	4	3	2	3	3	3	1
Que.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	2	1	2	3	1	1	1	3	4	1	2	1	1	3	3	2	3	2	2	4
Que.	61	62	63	64	65	66	67	68	69	70										
Ans.	4	1	3	3	2	4	3	3	1	5										